CpE 645 Introduction to Image Processing and Coding

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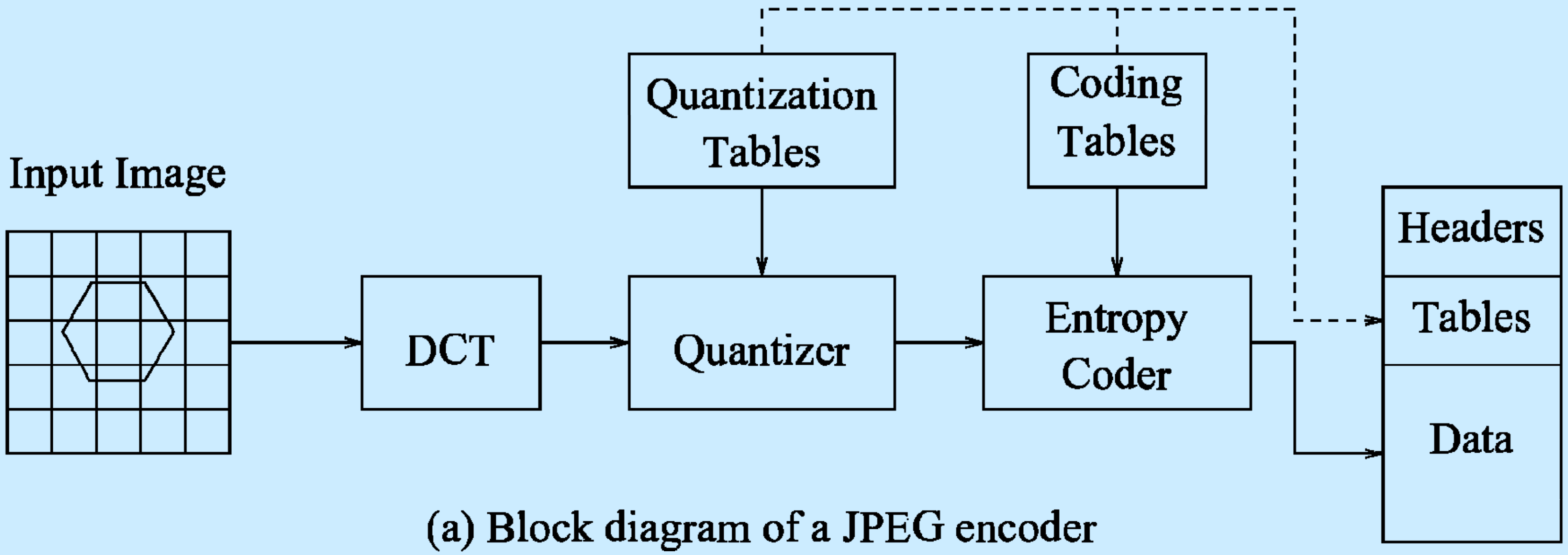
Lossy Still Image Coding

- DPCM approach: earliest and simplest non-PCM method.
- Transformation-Quantization-Entropy Coding approach:
  - Transform stage:
    - DCT based: JPEG
    - Subband/wavelet based: JPEG-2000
  - Quantization stage:
    - Scalar Quantization,
    - Vector Quantization.
  - Entropy coding stage:
    - Huffman coding,
    - Arithmetic coding.

The JPEG Standard

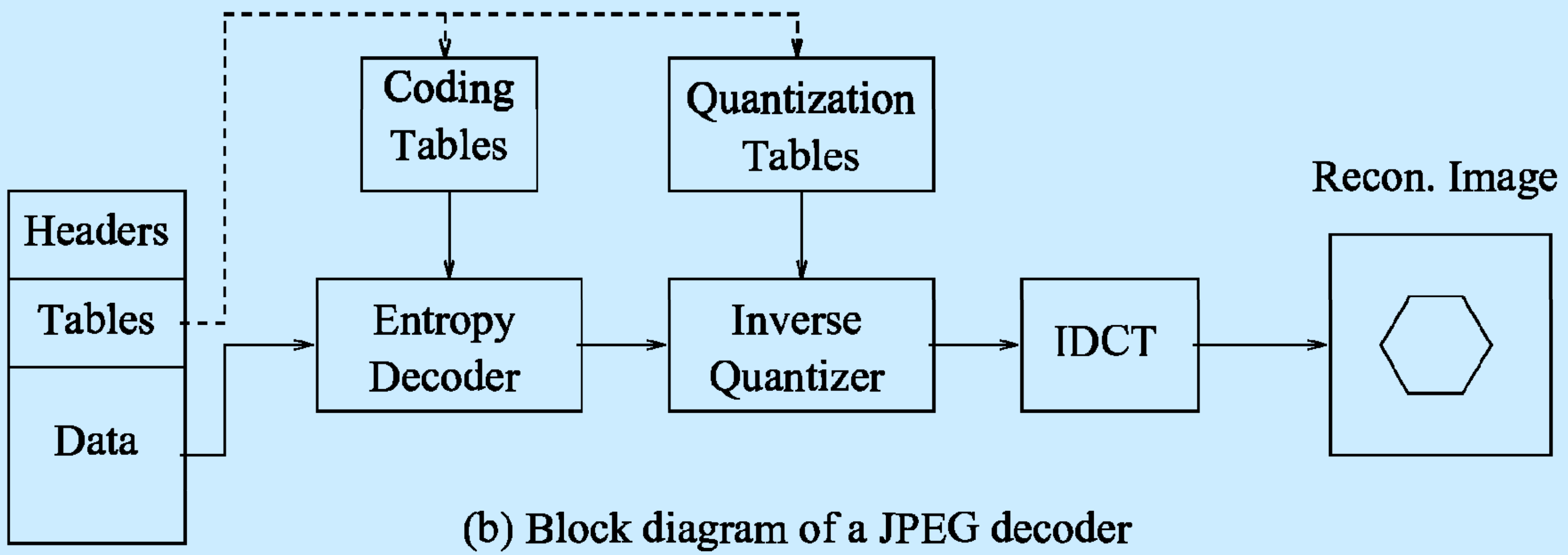
- JPEG: Joint Photographic Experts Group (ISO10918, ITU-T T.81).
- Requirements:
  - Generic still image compression
  - Modest to low software/hardware complexity,
  - Sequential, Progressive and layered coding.
- Features:
  - Psychovisual-based quantization,
  - Sequential, progressive/ hierarchical coding modes,
  - Relatively low memory requirement.

The JPEG Standard (*cont.*)



(a) Block diagram of a JPEG encoder

The JPEG Standard (*cont.*)



(b) Block diagram of a JPEG decoder

The JPEG Standard (*cont.*)

- Input of the coding process: 8x8 block, 8 bits/pixel.
- *Example:*

$$\begin{bmatrix} 175 & 172 & 172 & 173 & 169 & 174 & 171 & 167 \\ 171 & 170 & 170 & 174 & 177 & 175 & 171 & 166 \\ 167 & 168 & 172 & 174 & 169 & 172 & 174 & 161 \\ 149 & 149 & 156 & 153 & 148 & 149 & 155 & 141 \\ 101 & 106 & 105 & 107 & 99 & 92 & 106 & 97 \\ 73 & 74 & 72 & 71 & 65 & 70 & 79 & 72 \\ 72 & 71 & 67 & 62 & 62 & 72 & 80 & 71 \\ 68 & 70 & 64 & 58 & 62 & 73 & 74 & 67 \end{bmatrix}$$

The JPEG Standard (*cont.*)

- 8x8 DCT: the most computational demanding stage.
- *Example:*

$$\begin{bmatrix} 31144 & 52 & 35 & 86 & -294 & 264 & -137 & 14 \\ 8039 & 100 & -258 & 11 & 108 & 10 & 38 & -12 \\ -387 & -89 & 117 & 156 & -12 & -103 & 90 & -52 \\ -1778 & 47 & 96 & -78 & 59 & 10 & -31 & -19 \\ 164 & 80 & -7 & -43 & -8 & 0 & -6 & 12 \\ 551 & -17 & 54 & 18 & -67 & 64 & 47 & -3 \\ -152 & 4 & 6 & -16 & -30 & 24 & 15 & -34 \\ -83 & 19 & 12 & -37 & 6 & 15 & -46 & -6 \end{bmatrix}$$

The JPEG Standard (*cont.*)

- Quantization is performed using a quantization table (the Q-table).
- *Example:*

$$\begin{bmatrix} 16 & 11 & 10 & 16 & 24 & 40 & 51 & 61 \\ 12 & 12 & 14 & 19 & 26 & 58 & 60 & 55 \\ 14 & 13 & 16 & 24 & 40 & 57 & 69 & 56 \\ 14 & 17 & 22 & 29 & 51 & 87 & 80 & 62 \\ 18 & 22 & 37 & 56 & 68 & 109 & 103 & 77 \\ 24 & 35 & 55 & 64 & 81 & 104 & 113 & 92 \\ 49 & 64 & 78 & 87 & 103 & 121 & 120 & 101 \\ 72 & 92 & 95 & 98 & 112 & 100 & 103 & 99 \end{bmatrix}$$

The JPEG Standard (*cont.*)

- Let the **8x8** DCT coefficients $X[k_1, k_2]$ be the input of the quantization, and $Q[k_1, k_2]$ be the Q-table, the weighted DCT coefficients becomes

$$Y[k_1, k_2] = X[k_1, k_2]/Q[k_1,k_2].$$

- The output of the quantization stage is

$$\hat{Y}[k_1, k_2] = \mathrm{round}(Y[k_1, k_2]).$$

- A Q-table is designed to minimize the mean square error or maximize the visual quality.
- For a specific coding process, the prototype Q-table can be scaled with a factor in (**1~100**) to achieve different quality and compression ratios.

The JPEG Standard (*cont.*)

- The DCT coefficients are weighted by the Q-table.
- *Example:*

$$\begin{bmatrix}
1946.5 & 4.7 & 3.5 & 5.4 & -12.3 & 6.6 & -2.7 & 0.2 \\
669.9 & 8.3 & -18.1 & 0.6 & 4.2 & 0.2 & 0.6 & -0.2 \\
-27.7 & -6.9 & 7.3 & 6.5 & -0.3 & -1.8 & 1.3 & -0.9 \\
-127.0 & 2.8 & 4.4 & -2.7 & 1.2 & 0.1 & -0.4 & -0.3 \\
9.1 & 3.6 & -0.2 & -0.8 & -0.1 & 0 & -0.1 & 0.2 \\
23.0 & -0.5 & 1.0 & 0.3 & -0.8 & 0.6 & 0.4 & 0 \\
-3.1 & 0.1 & 0.1 & -0.2 & -0.3 & 0.2 & 0.1 & -0.3 \\
-1.2 & 0.2 & 0.1 & -0.4 & 0.1 & 0.1 & -0.4 & -0.1
\end{bmatrix}$$

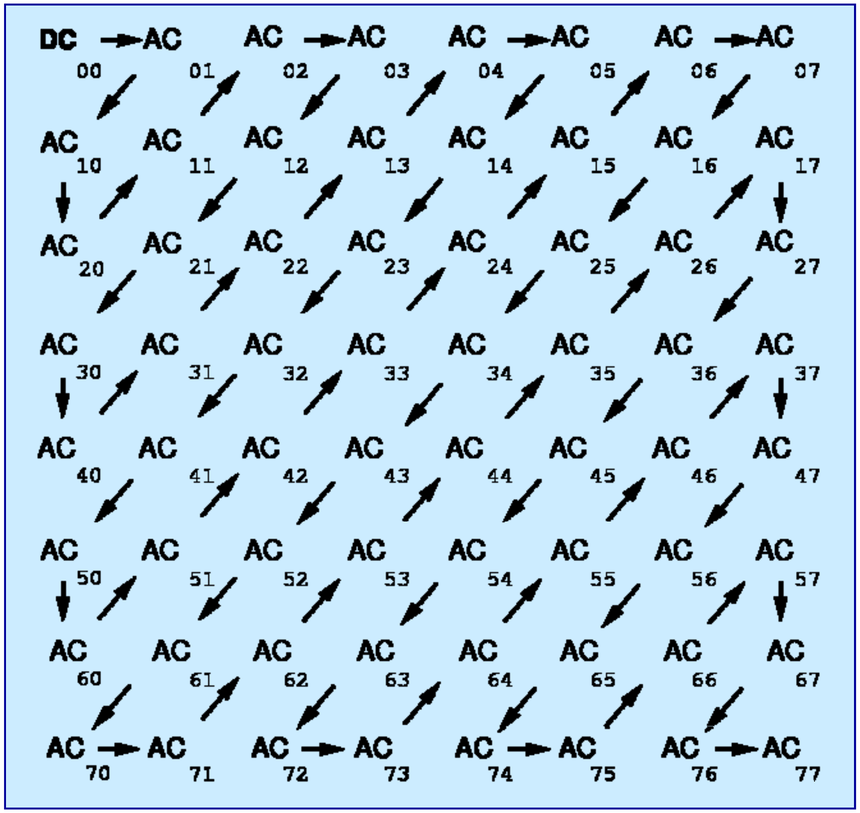
The JPEG Standard (*cont.*)

- The weight DCT coefficients are rounded to integers. The resulting block is then coded through the entropy coding.
- *Example:*

$$
\begin{bmatrix}
1947 & 5 & 4 & 5 & -12 & 7 & -3 & 0 \\
670 & 8 & -18 & 1 & 4 & 0 & 1 & 0 \\
-28 & -7 & 7 & 7 & 0 & -2 & 1 & -1 \\
-127 & 3 & 4 & -3 & 1 & 0 & 0 & 0 \\
9 & 4 & 0 & -1 & 0 & 0 & 0 & 0 \\
23 & 0 & 1 & 0 & -1 & 1 & 0 & 0 \\
-3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-1 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}
$$

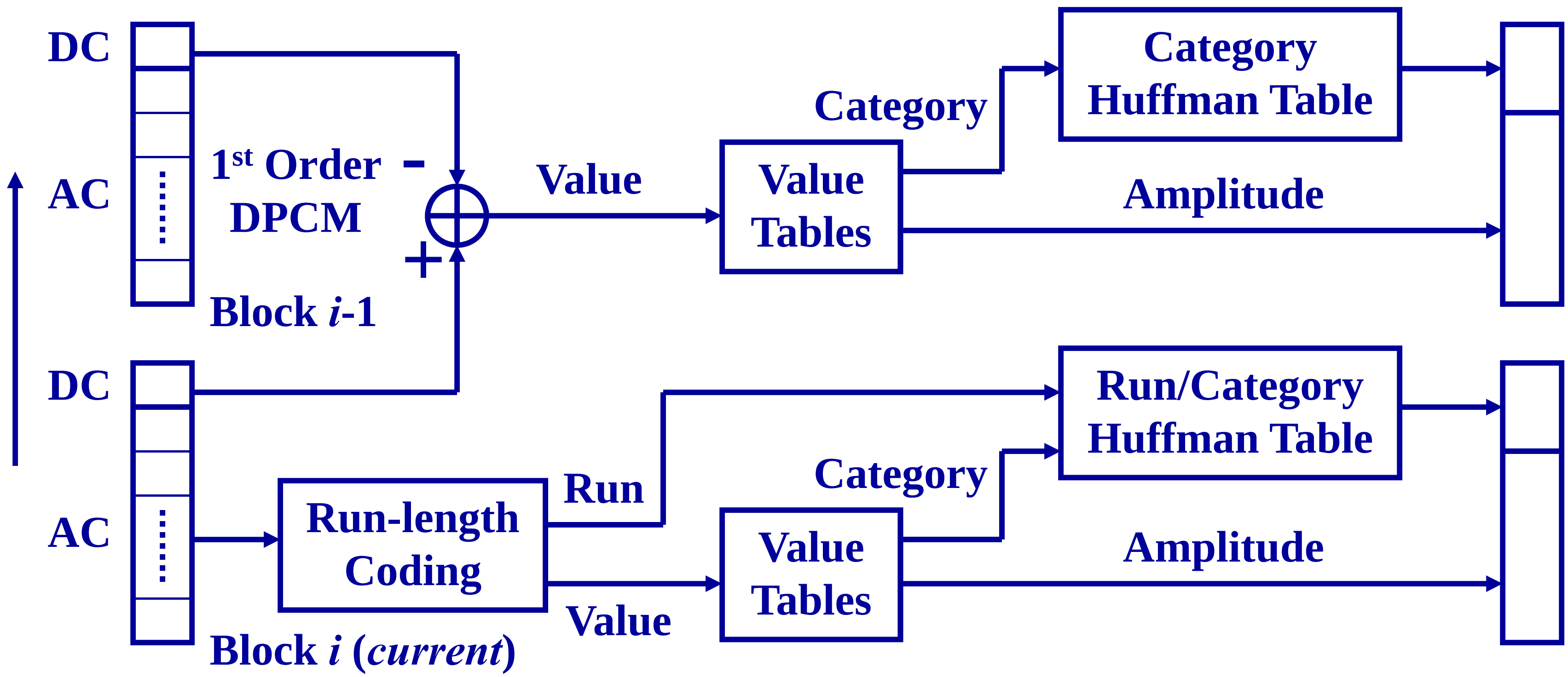
The JPEG Standard (*cont.*)

- Each quantized block is scanned through a zig-zag pattern and converted into 1-D data streams.



The JPEG Standard (*cont.*)

- The DC and AC bit streams are coded through Huffman coding together with DPCM and run-length coding.



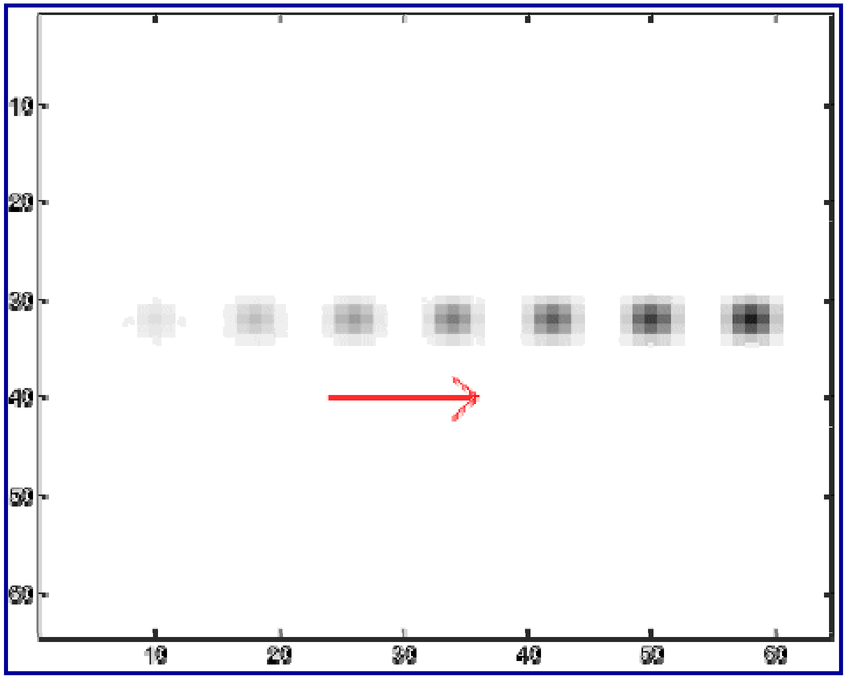
Digital Video

- Digital video is a sequence of still images (or frames) displayed at rapid succession.
- Digital video usually presents huge data volume:
  - NTSC video (720x480, 3-color, 30 fps): 249 Mbps.
  - HDTV video (1920x1080, 3-color, 30 fps): 1.49 Gbps.
  - Super-35 video (4096x3112, 3-color, 30 fps): 9.18 Gbps.
- Digital video compression is to exploit the data redundancies in both **spatial** domain (*i.e.* image compression) and **temporal** domain.

Example of Video Frames

Motion Representation

- Motion of an object or scene can be simplified and modeled as some ***linear motion***, in which a motion vector can be used to represent the motion.



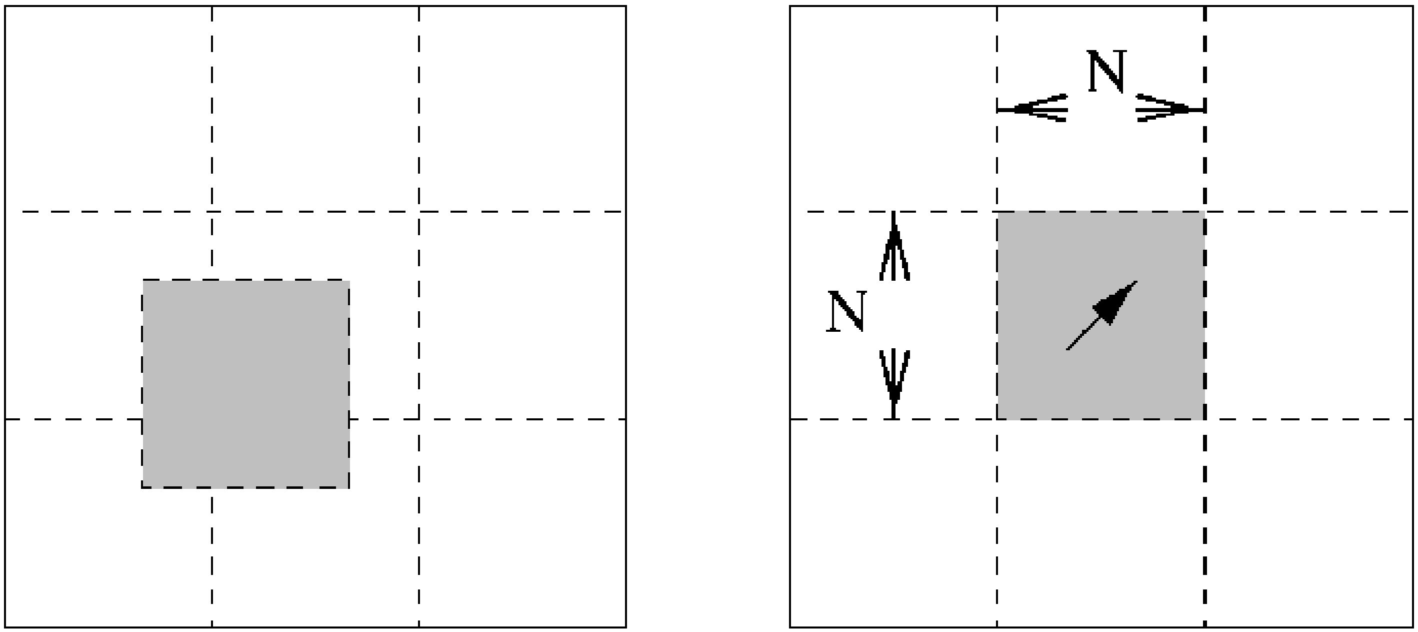
Block Motion Estimation

- In a complex nature scene, it is difficult to track all the moving objects.
- Block based motion estimation divides each video frame into fixed-sized non-overlapping blocks, and treat each block as an object to track its motion.
- A block in **current** frame is compared with all possible regions in the **reference** frame, this search will find a best match and produce a **motion vector** representing the displacement between the current block and its best match.
- The reference frame can be previous frame or future frame or both.

Block Motion Estimation (*cont.*)

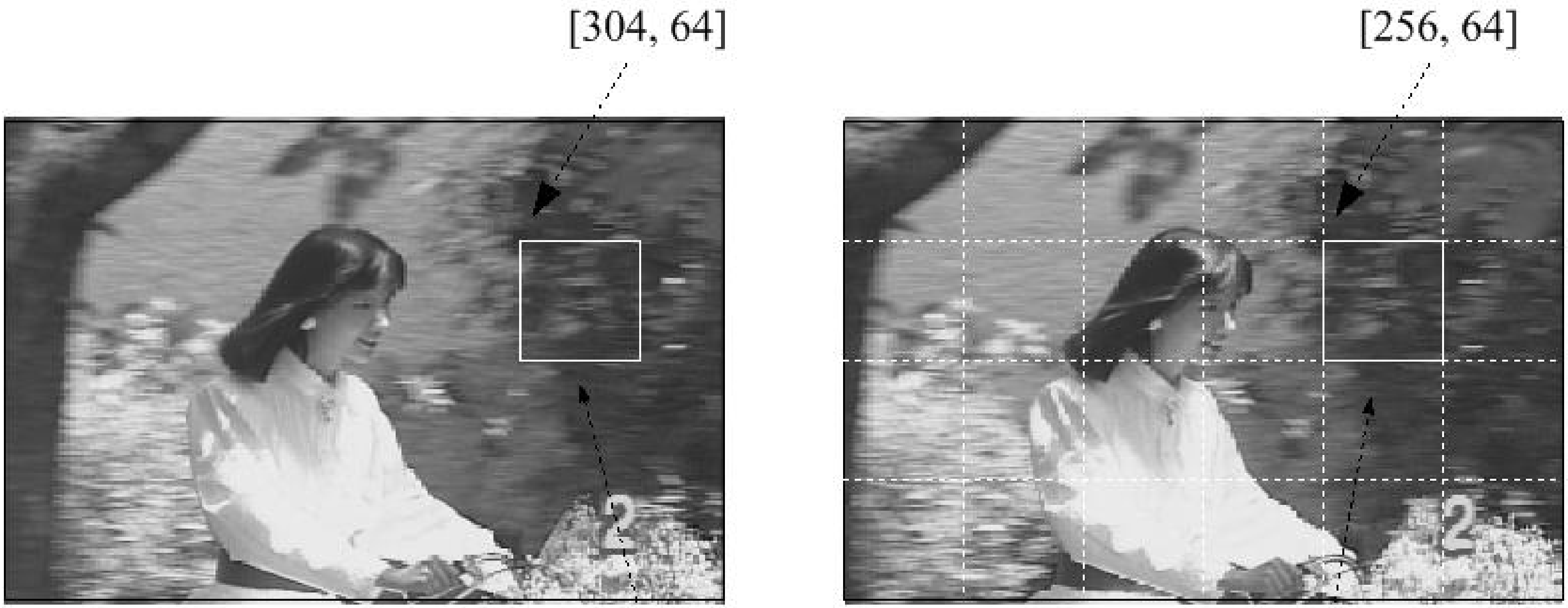
previous frame
frame i-1

current frame
frame i



(b) (a)

Block Motion Estimation (*cont.*)



reference frame

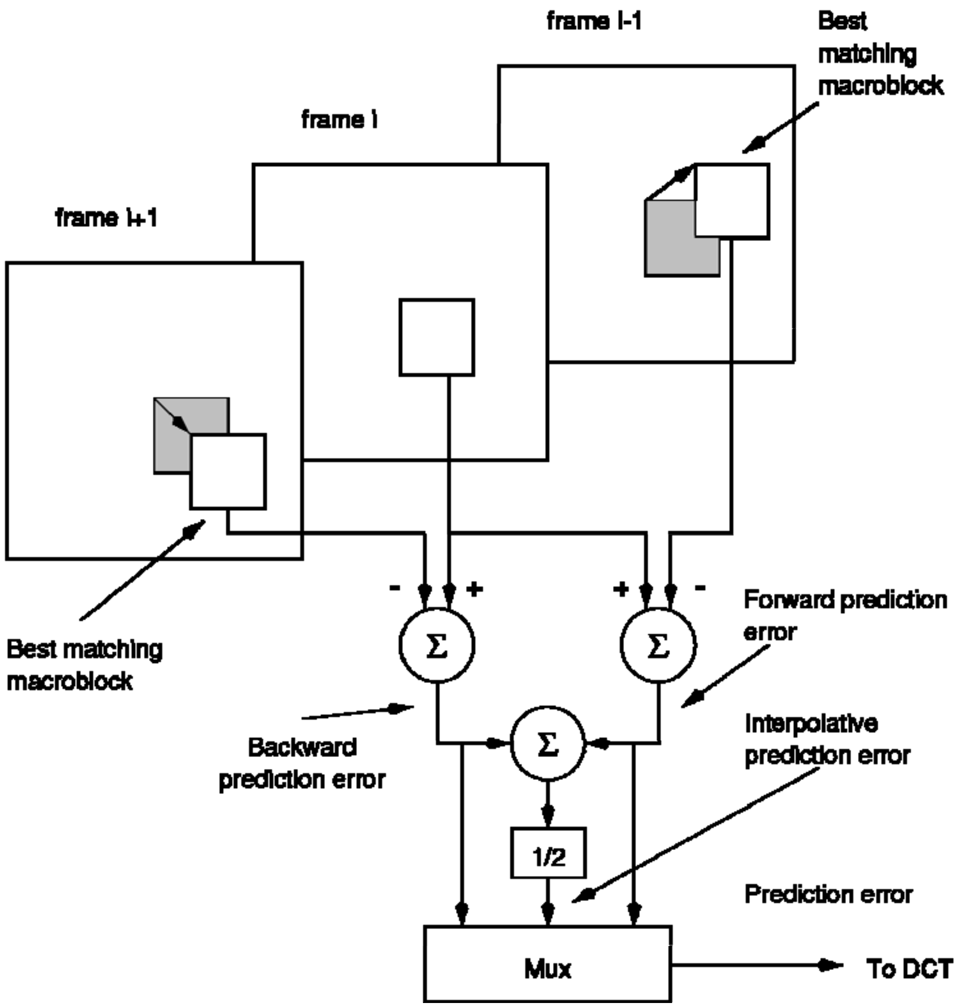
current frame

this reference block is selected as the
prediction block for this current block
with a motion vector of [48, 0]

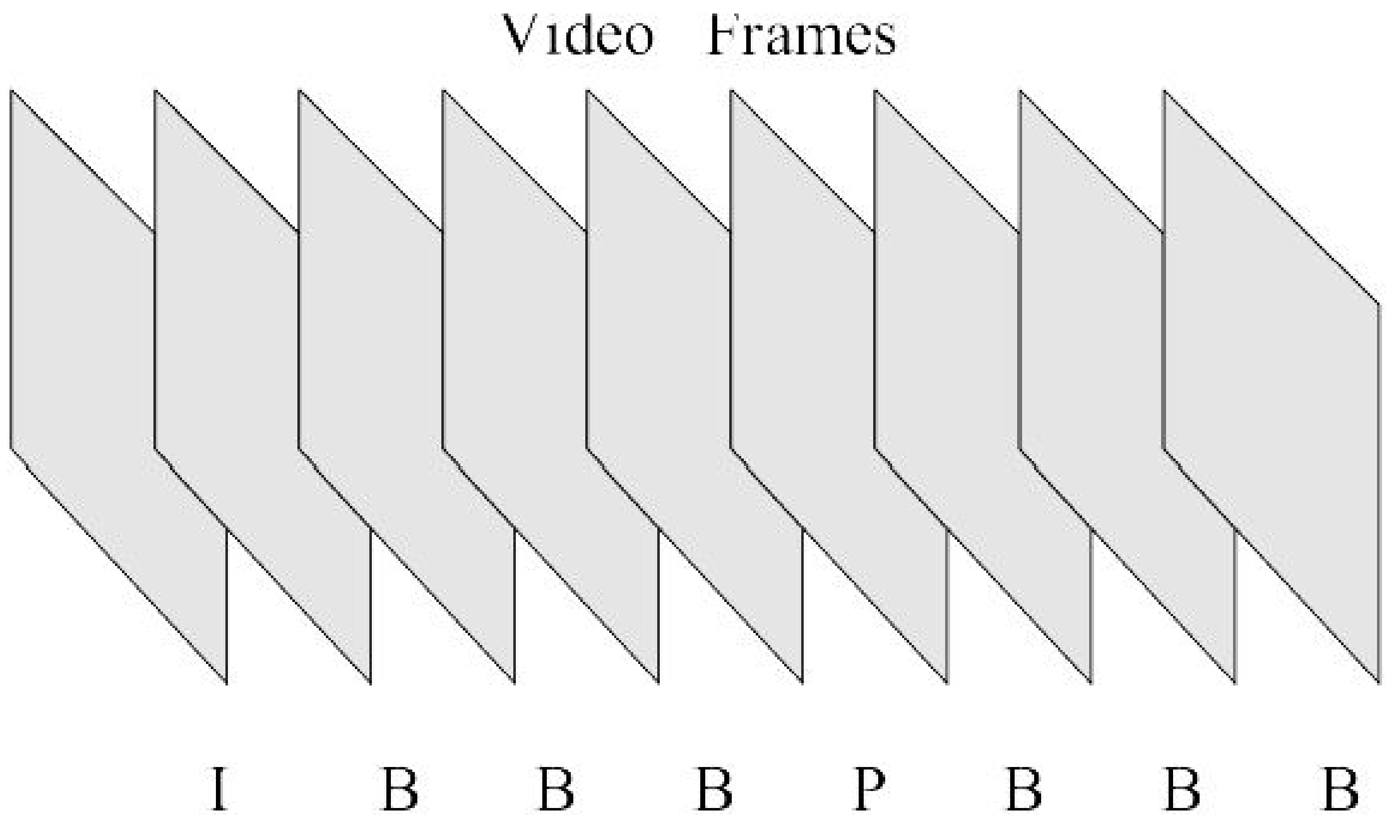
Motion Compensated Prediction

- **Motion compensated prediction** is a special prediction method based on the knowledge of motion in a video sequence. It can be used in a prediction coding structure.
- The procedure:
  - Block-based motion estimation, generating a motion vector for each block.
  - Moving the best match of each block to its current position to form a prediction block.
  - Deferential coding of each frame based on the prediction frame formed by all the prediction blocks.
  - Sending all the motion vectors to the decoder to generate the same prediction frame for decoding.

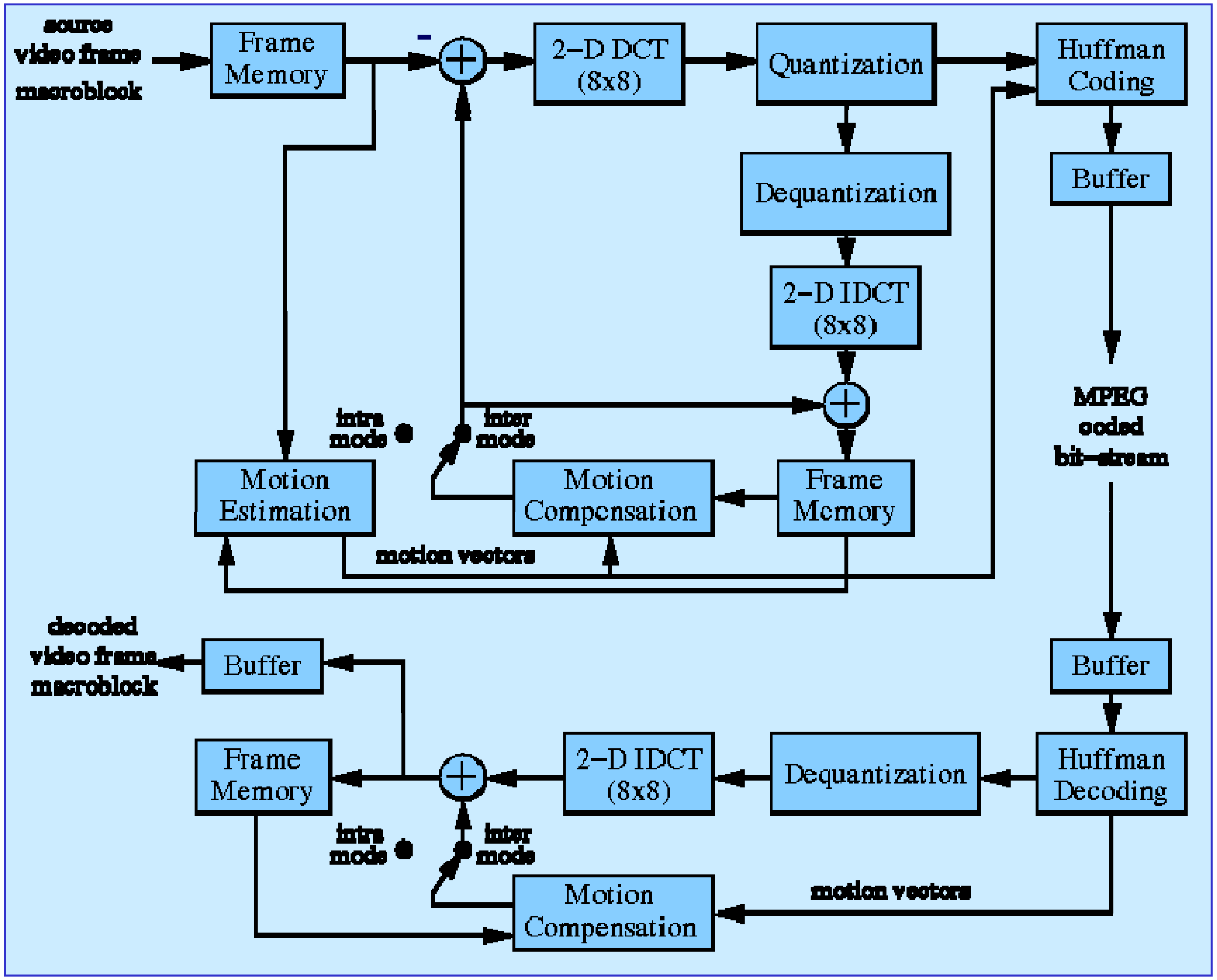
Bi-directional MC Prediction



I, P, and B Frames



Moving Pictures Experts Group (MPEG)



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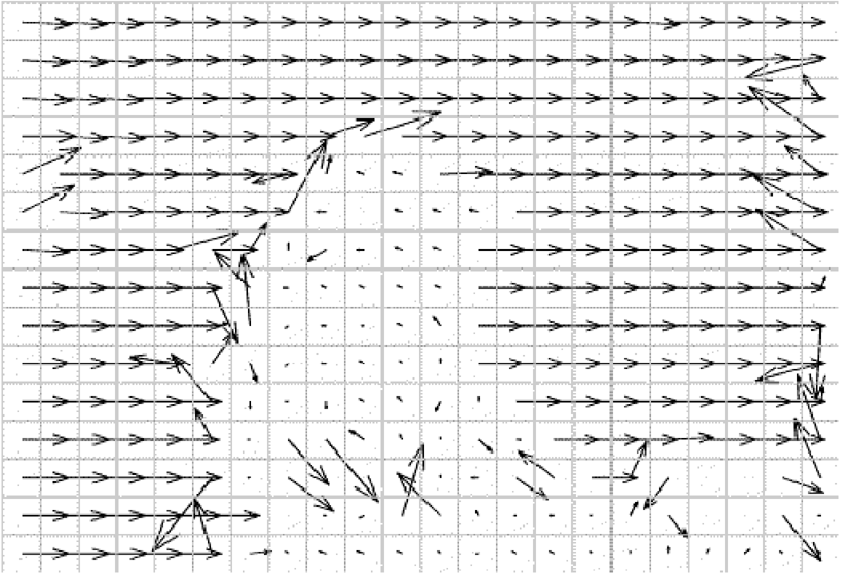
MC-Prediction: Example

Previous frame

Current frame

MC-Prediction: Example (*cont.*)



Motion vector field

Prediction of current frame

MC-Prediction: Example (*cont.*)

Residual frame with MC

Residual frame with direct difference

ITU-T H.261

- ITU-T H.261—The earliest video coding standard (1990).
- It is targeted for video teleconferencing over ISDN lines.
- Input formats: CIF (288x352) and QCIF (144x176).
- Bit Rate: multiples (1~30) of 64 kbits/sec.
- System delay is critical.
- Forward prediction only: I-, P-frames.
- A loop filter is used to reduce block artifacts.
- Bit stream structures: frames, group of blocks, macroblocks and block(8x8).

MPEG-1

- MPEG-1 — ISO standard 11172
  (11172-1: system, 11172-2: video, 11172-3: audio).
- Coding of moving pictures and associated audio for digital storage media applications.
- MPEG-1 is based on ITU-T H.261.
- It is optimized for 30 fps SIF format (352x240).
- Bit rate: ~1.5 Mbits/sec.
- System delay is not critical.
- Bi-directional motion estimation: I-, P-, B-frames.
- D-frame (DC) is supported for fast frame access.
- Bit stream structure: sequence, group of pictures (GOP), picture, slice, macroblock and block(8x8).

MPEG-2

- MPEG-2 — ISO standard 13818
  (13818-1: system, 13818-2: video, 13818-3: audio).
- Generic coding of moving pictures and associated audio.
- MPEG-2 is backward compatible to MPEG-1.
- Five **profiles** (algorithms), four **levels** (parameter sets) are defined for selecting in any specific application:
  - Profiles: simple, main, SNR-scalable, spatially-scalable, high.
  - Levels: low (352x288, 30fps, 4Mbps), main (≤720x576, 30fps, 15Mbps), high-1440 (≤1440x1352, 60fps, 15Mbps), high (≤ 1920x1152, 60fps, 80Mbps).

ITU-T H.263

- ITU-T H.263: Superior performance for very low bit rates.
- It is targeted for video telephony.
- H.263 is closely related with H.261.
- Bit Rate: below 64 kbits/sec.
- Forward prediction only: I-, P-frames.
- Hierarchical motion estimation.
- Differential coding of motion vectors.
- Support overlapping of motion vector blocks.

MPEG-4

- MPEG-4 defines a set of coding tools and a syntactic description for audio-visual objects (AVOs).
- Each of the AVO can be coded independently.
- Coding of object shapes is essential.
- Object-based motion compensation.
- Panoramic still background is coded using **sprite** coding.
- Still texture image is coded using wavelet coding.
- Supporting SNR-, spatial- and object-scalability.
- Server-side interaction: content-based manipulations.
- Client-side interaction: AVO modifications.
- Much more…

DVD-Video

- DVD specification is defined and maintained by DVD Forum (http://www.dvdforum.org/forum.shtml).
- DVD-Video storage capacity 17 Gbyte if two layers on both sides of the disk are utilized.
- Specifications and features
  - 133 minutes of high quality MPEG-2 encoded video with multi-channel Dolby Surround AC-3 audio can be stored on one layer on one side (around 4 Gbyte).
  - Support widescreen, letter box and pan & scan video formats. (4:3 and 16:9 aspect ratios).
  - Up to 8 tracks of digital audio for multiple languages, each with as many as 8 channels.
  - Up to 32 subtitle/karaoke tracks.

DVD-Video

- Specifications and features
  - Menus and program chains for user interactivity
  - Up to 9 camera angles to give the user more choice
  - Digital and analogue copy protection
  - Parental control for protection of children
  - Special effects playback: freeze, step, slow, fast, and scan (no reverse play or reverse step).
  - Random play and repeat play.
  - Programmability (playback of selected sections in a desired sequence).

DVD-Video

- Content Scrambling System (CSS)
  - CSS is a data encryption and authentication scheme intended to prevent copying video files directly from DVD-Video discs
  - The CSS decryption algorithm exchanges keys with the drive unit to generate an encryption key that is then used to obfuscate the exchange of **disc keys** and **title keys** that are needed to decrypt data from the disc.
  - DVD players have CSS circuitry that decrypts the data before it's decoded and displayed.
  - In October 1999, the CSS algorithm was cracked and posted on the Internet, triggering endless controversies and legal battles

DVD-Video

- DVD regional codes:
  - Motion picture studios want to control the home release of movies in different countries because theater releases aren't simultaneous
- More info about DVD-Video

http://www.disctronics.co.uk/technology/dvdvideo/dvdvid_intro.htm

http://www.dvddemystified.com/dvdfaq.html